Knowledge-based situational awareness systems

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***Abstract* – In this paper are described the methods of representation and processing of knowledge in systems with situational awareness. The Endsley's model and Data Fusion model are described and analyzed. Also, in this paper we analyze the ontologies for situation awareness. The core ontologies are described using combination of primitive relations. Existing issues and further research problems were outlined.**

Key words – situation, situational awareness, decision support, data fusion model, core ontology, primitive relation.

I. Introduction

Situational awareness (SAW) is an important part of human's cognitive activity. Not surprisingly, it has always been the subject of the research in the scientific fields of psychology, cognitive science, artificial intelligence, decision-making theory, systems theory, knowledge-based systems, robotics.

During the First World War the concept of situational awareness was identified by pilot and military tactician Oswald Boelke. He argued that "the importance of gaining an awareness of the enemy before the enemy gained a similar awareness, and devised methods for accomplishing this" [1].

The idea of separation between the understanding of the state system by human operator and the actual state of the system underlies the modern definition of situational awareness. By the end of 1980 situational awareness has not received much attention in the technical and scientific literature but has since become a hot topic of research.

The research in the area of situational awareness is based on previous research and formalization of notion of situation by Barwise [2] and other researchers. They created a Situation theory as a part mathematical theory of meaning. Devlin [3] clarified the relation between situation theory and information, he showed that the information is always associated with some situation.

The first research of situational awareness as part of a decision support system was conducted for military, aircraft and other complex human-machine systems to provide the operators with information [4]. Actually in such systems the value of possible error is very large, and the operator must take into account many factors in the decision.

Situational awareness is a key element in decision support systems. In particular, in most cases, if the situation is properly evaluated, it automatically determines the sequence of actions you want to initiate [4]. Methods for identification of critical situiations allow to capture, formalize and reuse the knowledge of experts about those situations.

Nowadays, the task of achieving situational awareness is especially important in context of development of autonomous decision making systems and Internet of Things (IoT).

Solving this problem needs, in turn, in-depth study of existing and development of new principles and methods of knowledge formalization of problematic situations, models of their processing, creating organizational, informational and software tools related to decision support.

II. Models of situation awareness

To determine the components of the SAW and its place in the process of solving cognitive tasks were developed a number of SAW models.

Endsley [5] first proposed a generic model of situational awareness in terms of information processing (Figure 1) by human operator. She suggested that SAW can be divided into three levels or stages of mental representation.

Level 1 – perception

Perception of signals is fundamental. Without basic perception of important information the chances of forming an irregular picture of the situation rise steeply. Jones and Endsley (1996) found that 76% errors of pilot situational awareness are reduced to the problems of perception of necessary information (resulting in the violation of system operation or disadvantages and problems with cognitive processes).

SAW is the decision maker's perception of the status, attributes, and dynamics of relevant elements in the environment (the decision situation). So level 1 is the lowest and most basic level of SAW. Achieving this level SAW involves basic information detection processes.

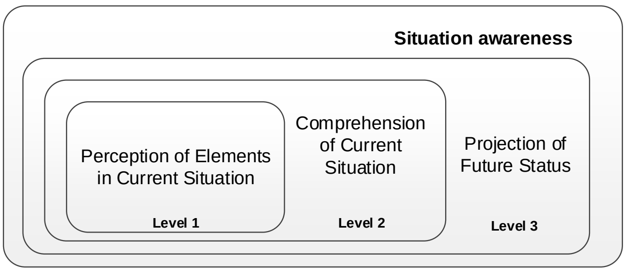

Fig. 1. Endsley's model of situation awareness

Level 2 – comprehension

Situation awareness as a concept goes beyond mere perception. It also covers how people connect, interpret and store information. Thus, it includes more than perception or paying attention to information, but also integrating the multiple pieces of information and determining their relations towards human goals. This is analogous to the high level of comprehension when reading text compared to just reading words.

So SAW is the decision maker's comprehension of the perceived information, i.e., Level 1 SAW. Level 2 SAW is achieved through pattern recognition, interpretation, and evaluation. Level 2 SAW results a comprehensive picture of the environment.

Level 3 – projection

At the highest level, the operators have a high level of understanding of the situation and have the ability to predict future event of the situation and dynamics of the system. This ability to project current events and their dynamics to predict future events and their consequences, creates opportunities for timely decision making. In almost all areas (aircraft, air traffic control, power stations, medicine) was found that most experienced operators rely on forecasts. This is a sign of a qualified professional.

Today, SAW is considered to be a part of Data Fusion process, which has a goal of integrating data and information from different sources. Data Fusion itself is used in several contemporary scientific endeavors, such as Big Data.

The Data Fusion Model was developed by the Joint Directors of Laboratories Data Fusion Group, a US DoD government committee overseeing US defense technology. The stated purpose for that model and its subsequent revision has been:

- to categorize different types of fusion processes;
- to provide a common frame of reference for fusion discussions;
- to facilitate understanding of the types of problems for which data fusion is applicable;
- to codify the commonality among problems;
- to aid in the extension of previous solutions;
- to provide a framework for investment in automation.

It should be emphasized that the JDL model was conceived as a functional model, not as a process model or as an architectural paradigm. A characteristic feature of the Data Fusion model is an abstraction from operations data collection, situation assessment and decision previously made only by human-operator which enables the analysis of SAW for human-machine systems, and purely autonomous systems.

In 1988 White published an article in which he proposed a Data Fusion Model [6]. In 1998 Steinberg, Bowman, and White developed the first paper formally addressing various extensions to the Data Fusion Model [7]. That paper began by revisiting the basic definitions of Data Fusion both conceptually and in terms of the "Levels" that are characterized in the original JDL model.

Expanded Data Fusion Model has the following levels:

- Level 0: Signal/Feature Assessment - estimation and prediction of signal or feature states;
- Level 1: Entity Assessment - estimation and prediction of entity parametric and attributive states (i.e. of entities considered as individuals);
- Level 2: Situation Assessment - estimation and prediction of the structures of parts of reality (i.e. of relations among entities and their implications for the states of the related entities);
- Level 3: Impact Assessment - estimation and prediction of the utility/cost of signal, entity or situation states - including predicted impacts given a system's alternative courses of action;
- Level 4: Performance Assessment - estimation and prediction of a system's performance as compared to given desired states and measures of effectiveness.

III. Situational awareness based on ontology usage

Situation awareness was envisioned as the main part of Level 2 processing in the JDL model [6,7]. But only recently has it become the center of attention for information fusion research. As is typical with a new field of research, various studies on this subject have contributed results that are difficult to integrate into one coherent conceptual structure. In other words, the field of situation awareness needs a unifying framework that would play the role of a common theory integrating various research efforts.

Moreover, the existing trends of development of intellectual systems determine the need to change the focus of the research of human-machine systems to a fully autonomous intellectual systems capable to navigate and make decisions in real situations.The main bulk of research on SAW pursued until now, has focused on developing SAW in systems with human operator and his support decision making. These research were based on models and take into account the peculiarities of human cognitive processes. Research of purely computer process of SAW needs other models. The computer situation awareness process still lacks a more systematic treatment.

Clearly it is necessary to develop unambiguous specifications, designs and implementations of situation awareness processes. One of the trends in this direction that became prevalent in recent years is that of using ontology-based computing as a paradigm on which to develop computer based situation awareness processes.

Situation awareness enables an intelligent agent to determine the meaning of perceived information in highly dynamic environments and to share the thereby discovered knowledge. In order to effectively reuse knowledge we need to identify the concepts and relations common to multiple domains. This common knowledge is codified in upper ontologies.

Ontology-based approaches to situation awareness facilitate the development of upper ontologies in order to provide a common vocabulary for collaborating agents and information sources.

In particular, in [8] is described an attempt to develop formal language representation of SAW, which would be understandable to the human and suitable for computer processing. The author developed the means to transform the mathematical description of the situation using infons in formal ontology description using OWL language. The operating result is Situation theory ontology (STO), which can play the role of a common theory for machine systems with SAW. Authors also present examples of logical inference using the STO ontology.

On the other hand, researchers of situation awareness systems have realized that there are an entities and relations independent of the subject area and are common to all systems of situation awareness

To build a unifying ontology for SAW, which can be re-used for different domains we must first of all define such common elements and on their basis to build basic core ontology.

In paper [9] the core ontology and its expressiveness were proposed and analyzed. Also its suitability for expansion by introducing new entities and relationships was demonstrated.

The relationship that exist between objects in domain traffic control situations aimed at determine dependencies were analyzed by authors in [10]. According to such relation characteristics as the ratio of its frequency of use and dependence on domain were identified four types of relations (Figure 2): Primitive, Leading, Situational, Nominal.

In this paper was shown that complex, independent of domain relation may be submitted as a combination of primitive relations. So in fact the primitive relationship, including time and space should be used to build core ontology SAW.

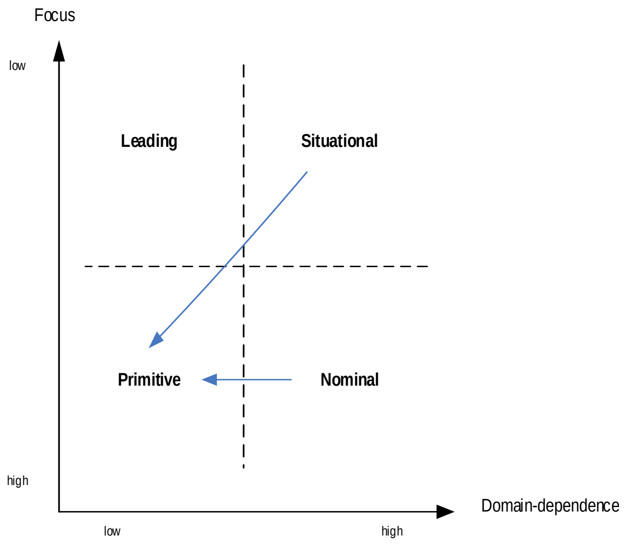

Fig. 2. Classification of Relations

The practical advantages of incorporating primitive relations into a framework for SAW are threefold. First, one may develop to some degree domain-independent as well as optimized relation derivation algorithms which can be reused in a specific domain. Second, situational relations can be derived by explicitly using existing primitive relations. That is, one may abstract from the details of space, time, etc. and concentrate on the specifics of the to-be-derived situational relations. Finally, the strictly top-down approach, which leads to the deterministic view of relations that contribute to situations, may be levered. That is, by rating relation types according to the degree of their contribution to a situation, also exceptional cases could be dealt with.

In [11] is proposed a framework for comparing existing upper level ontologies for SAW with a purpose of better understanding of different approaches to SAW ontologies construction and also to find missing features. Author devided existing SAW ontologies into three groups. First one (largely based on Sowa works) represent upper level, partially obtained from general ontologies. Second one codifies SAW-specific concepts, uses situational theory of Barwise and JDL data fusion model. This approach provides a better understanding of SAW. Third group is related to results of knowledge modeling within Cyc project. This group also provides such important criteria for SAW ontologies comparizon as universality and articulation.

Conclusion

Despite the popularity of scientific area of situation awareness and a large number of works, SAW research remain actual. This is because of existing trends in decision support systems, the development of autonomous intellectual decision support systems, increased situation awareness requirements for industries such as business analytics and others. A significant number of problems are researched insufficiently. In every part of the field of situation awareness exist the unsolved problems and challenges that require further deep research.

In particular, the issue of data and knowledge representation in system. Despite the fact that now a common is an ontological approach to knowledge representation, there are problems with the representation and processing of time and space data and knowledge. Further research is required in the problem of systematic approach to the creation, modification and expansion of ontology in systems with SAW.

Also in our opinion the area of researching relations in SAW, their formalization, transformation, storing and retrieving, processing as well as reasoning using relations requires additional efforts. This is especially important because situations are described by set of relations.

The dynamic nature of environment where SAW system operates combined with necessity to take in consideration resource limitations and high performance requirements, makes the implementation of system with SAW a really hard technical problem. In order to solve it, the study of heuristical methods in decision making, formalization of corresponding knowledge is required. The approach of ontological modelling for processing heuristical knowledge looks promising.

Another possible area of future research is related to necessity of deeper understanding of change dynamics in environment where SAW system operates. The operators of such system often need to know not only when environment parameters are in the 'red' area, but also when they are in the bordering area, and transition to 'red' area is highly probable. Moreover, desirable is to know aforetime when 'red' zone can be reached in several steps from current state, taking in consideration current trends in order to take early mitigation actions.

Another problem is the limited, incomplete, uncertain information about environment. In [12] is provided the analysis and classification of different types of uncertainty with a purpose of selecting most suitable formalisms for SAW systems to represent and process uncertain knowledge. However, the general problem of correct situational assessment taking into account the different types of incomplete information has not been solved yet.

The actual problem is also problem of measurement of the quality of SAW. Existing research [13-15] focuses on SAW performance measures defined within the parameters and limitations of the human operator and its cognitive processes. It is clear that this approach is not suitable for assessing the quality of SAW in the autonomous intellectual systems. The task of conceptualization and building a common approach to assessing the quality of SAW in different types of systems and problem domains needs to be further researched.

Creating situational awareness is often considered as preparing information for single decision maker. However, in more general situations, information about current situation is collected by multiple agents and this information is also used by multiple decision-making agents. It is a common approach to use interpreted systems [16] for formalizing and modelling SAW in multi-agent environment. The reasoning about agent's knowledge is done using epistemic logic. However, the tasks of building distributed ontologies, organizing knowledge sharing and integration across different agent's local knowledge also is important.

Formation of situation awareness is a prerequisite for the organization of context-dependent computing where actions depend on the state of the environment. In [17] is described context-dependent decision making system. In [18] is presented a context-dependent tourist service which takes in consideration emotional state of tourist and other factors when selecting exhibit information. It uses an ontological approach to build SAW. The problem of general theoretical understanding of a place of situation awareness in the context-dependent computing remains open.

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